EUROPEAN COMMISSION

Community research

This Project has received funding from the European Union's European Atomic Energy Community's (Euratom) FP7 under grant agreement n°269905, the LUCOEX project.

LUCOEX

(GRANT AGREEMENT: 269905)

DELIVERABLE (D-N°:D1:13)
LUCEX END CONFERENCE - Observations of Scientific Rapporteurs

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Date of issue of this report: **01/09/2015**

Start date of project: 01/01/11 Duration: 56 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)		
Dissemination Level		
PU	Public	**PU**
RE	Restricted to a group specified by the partners of the LUCOEX	
CO	Confidential, only for partners of the LUCOEX project	

EURATOM

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1 Introduction

The conference and workshop was opened by Magnus Westerlind, SKB, and then followed by a keynote speech of Christophe Davies, EC, who presented news from the European Commission with regard to ECs Energy Policy as a reaction on Climate Change. On basis of this policy the R&D-Programme HORIZON 2020 was set up two years ago, which he explained in detail and eventually promoted participation in the next call for proposals at the end of the year. He emphasises that EC continuously did and will support national programmes on geological disposal by providing budgets for RD&D; and he underlined that IGD-TP has a key role to play in the evolution of EC RD&D policy.

1.1 Session 1: National Programmes of DGD

Session 1 consisted of 4 presentations all of them dealing with the status of the National Programmes of Deep Geological Disposal (DGD). Two presentations were dealing with Deep Geological Disposal in crystalline rock whereas the other two were describing the programmes for a DGD in clay formations.

SKB described the Swedish spent nuclear fuel repository project development from the beginning in the late 1970ies until the status as of today. Eventually, in 2010, Forsmark (host rock: crystalline rock) was selected by SKB as a suitable site. The following year, the license application was submitted and is currently being processed. Start of repository operation is expected in 2029. Two main challenges were mentioned. On the one hand side the flexibility of the licensing process with regard to conceptual modifications is an important issue which requires appropriate timing. Despite of the strong public support (85%) today the challenge will be to keep a continuity of the support in particular during the phase of industrialisation of the facilities and the programme.

Posiva gave a presentation of the Finnish waste management programme for spent nuclear fuel from the beginning until today. The programme started in the late 1970ies with preliminary studies followed by a site selection process and the decision on the site Olkiluoto in 2001. In 2012, the application for the construction of the repository was submitted; a decision is expected in autumn 2015. In the course of the discussion with the authorities STUK requested an RD&D-plan on demonstration tests. These tests are being or will be performed in ONKALO. The challenge will be to successfully demonstrate safe and reliable waste package transport and emplacement as well as suitable plugging and sealing systems. Important news is the decision to use a shaft instead of a ramp for the waste package transport.

ANDRA described the evolution of the French waste management programme which considers the disposal of reprocessing waste only. The potential site in a Callovo-Oxfordian (COX) clay formation will be in the vicinity of the URL at Bure. An appropriate repository project- called Cigéo – was launched. This includes siting in the context of public participation as well as industrial preliminary repository design. In 2017, this design will be accomplished and the application for license will be submitted. The URL Bure is and will be used to qualify the processes and technologies and to perform investigations at an industrial scale. The major challenges are the setup of a detailed RD&D-programme which includes the waste transport and handling demonstration tests under real repository conditions. The industrial pilot phase of Cigéo is of uppermost importance and will start in 2015 followed by the first emplacement in 2028.

NAGRA presented in detail the approach to how to find a site for a Swiss HLW repository and explained the status as of today. In 2008 a new site selection process (sectoral plan) was launched which first started with the definition of rules and the agreement with stakeholders on their participation. The stepwise approach led to 6 potential regions in phase 1 and in dialogue with stakeholders in two of the regions in the following phase 2. A decision of the government for the next phase is expected in 2017. The most important lessons learnt were that a strong driver of the repository site selection and implementation process is required to keep the programme on track. And the involvement of stakeholders is very important. The stakeholder engagement may have impact on the decision of single repositories for ILW and HLW or a combined repository for both waste categories.

2 Session 2: Full scale tests

Session 2 consisted of 12 presentations describing LUCOEX, DOPAS, PRACLAY and FEBEX experiments; links to MODERN programmes were also discussed. The fact that results of different programmes are presented at a special event devoted to a single EC project is seen as positive; DOPAS & LUCOEX experiments are complementary, their results are to be shared. Interesting is also confrontation of nearly completed long term FEBEX with newly starting experiments.

Presentations delivered treated the following topics:

2.1 Backfilling & sealing

Performed experiments have served to demonstrate the technologies to manufacture, handle and place the sealing components of the disposal system. This has included the development of the necessary equipment and relevant procedures.

The experience gained has resulted in optimisation of material composition to achieve better performance during manufacturing, storage, handling and placement of the sealing components. Bentonite sensitiveness to humidity is a well-known issue; however, some ways how to manage this problem were reported, including adoption and control of the manufacturing/handling procedures, optimising bentonite water content and the relative humidity of the air, the density and the grain size (see also presentations delivered within the Session 4). It has also been identified that rings and end blocks around canisters should preferably have harmonised water contents in order to improve handling and storage. Indications are that this should be possible with the bentonites currently used.

To achieve the required final homogeneous density of bentonite backfill, grain size and dry density of the used pellets need to be optimised and homogeneous material be used. Certain local variations (e.g. between bottom and roof section, and between different batches) have not had impact on the target average density of the whole seal. It was recognized during testing campaigns that the swelling effect of bentonite was slower than anticipated. The role of systematic pre-testing is vital for the successful emplacement procedures during the full size experiment.

Technologies for the emplacement of sealing materials, both in powder/pellet and block forms has been developed and proved. However, some findings (e.g. wear of screw conveyors) have indicated the need for further optimisation of these technologies and the equipment involved. They may result in changing equipment designs and optimising the procedures applied.

The use of very big blocks, over 2.3 meters in diameter, has not been seen as an optimal method for backfilling of horizontal emplacement tunnels in clay due to handling difficulties and the need to fill in gaps between the blocks and the rock surface which is not normally smooth and regular. In such case, the use of continuous mixture of pellets and powder seems to be more feasible. Another direction to be further investigated consists in the selection and perfecting of excavation tools and methods to achieve better contact between the seal and rock.

The major achievements could be formulated as follows:

- Design basis for plugs/seals have been developed – the proven approach and methodology are applicable to other repository elements
- Feasibility of full scale sealing has been demonstrated, and
- Manufacturing and handling large sealing components has been found feasible.

2.2 Instrumentation and monitoring issues

The major problem regarding monitoring the system performance in these experiments is the limited longevity of the sensors and especially the wireless technology that have been utilized. Therefore, it has been deemed necessary to install spare wires and sensors to ensure that experiments can be evaluated and interpreted during their whole duration (1-2 decades).

Specific materials and designs are needed for better performance of sensors, specifically to improve the temperature and corrosion resistance. In particular, the energy supply to sensors and transmitters for decades is still a challenge. Wireless transmission and the use of fibre optic cables are potential promising solutions but they need more development, specifically for maintaining their function over period of a couple decades.

Radiation effects are not considered for the current systems, however, in future monitoring of real disposal system it will also be a challenge.

There is still contradiction regarding timing: while monitoring of a closed disposal system can work for some decades, the real disposal system will reach equilibrium after centuries. Hence, there is a need to arrive at a common opinion on whether to monitor and, if affirmative, what, why, and how to do it.

Monitoring approaches have been and are being more elaborated within the EC MODERN projects: the tight cooperation would be beneficial for participants of both projects.

2.3 Heating

The heating sequence of experimental systems has not followed real anticipated conditions: the thermal load increase was controlled in steps to better understand the system performance and response under elevated temperature; it has been found satisfactory and the THM response to heating was under full control. Nevertheless, the thermal shock of host engineered and natural systems when disposing real container would need also to be investigated.

It shall be noted that the 'historical' temperature limit of some 90 °C for bentonite sealing has been challenged: instead, the overheating to some 130-150 °C with the evaluation of functional consequences for the disposal system is a new – and positive - strategy in some concepts.

2.4 THM-Modelling

THM modelling is generally considered as a tool supporting repository design. In particular, modelling is part of the pre-testing experiments: the values predicted were mostly consistent with real measurements in small scale. However, some discrepancies were found in modelling of the near-field of the full scale experiments where the swelling in real systems is slower than anticipated, thus, full scale experiments may require artificial watering of the bentonite layer. Comparison of mathematical predictions with real system performance will certainly help in validation and optimisation of the used modelling approaches.

Another issue requiring attention is that a real system will be affected by overlapping thermal fields from individual disposal cells where the bigger thermal gradient could create more severe consequences.

2.5 Planning and installations

A good example of systematic planning of large scale experiments has been demonstrated at starting DOPAS, terminating FEBEX, and delayed PRACLAY projects: all these approaches can be effectively shared with less advanced programmes.

Within DOPAS, design bases for plug/seal demonstrators were defined and iteratively developed prior the start of experiments and collated for each DOPAS experiment. They include information on safety functions for particular host rocks, requirements on hydraulic, chemical and mechanical performance and on gas migration, operational constraints, working practices, environmental conditions/impacts.

One of the first full scale experiments, FEBEX, was initiated in 1995 by ENRESA. Heating started in 1997, a part of the experiment was dismantled in 2002 and the remaining part is to be dismantled in 2015. Planning for dismantling started together with modelling predictions of the system performance based on partial dismantling experience. Detailed planning was initiated some 2 years prior anticipated start. It was broadly discussed among involved organisations and, later, also with new invited partners. As a result, the detailed plan for dismantling operations and sampling was proposed considering principles and experience from 2002 dismantling.

The PRACLAY test had originally to start in 1995, but it was delayed due to the necessity of the sinking of the 2nd shaft, waiting for bentonite hydrating, etc.; as a result, heating was initiated in 2014. As a consequence, experiment conditions and ideas were changing over time (design, staff rotation, material demands, availability of contractors, regulation evolvement). The key issues to be maintained included the need for keeping knowledge (knowledge management), assuring continuity of the staff capabilities, and the management of requirements. The most challenging was to keep track of all documents and information collected in preparatory stages of the document. Bentonite hydration was slower than anticipated. Any planner should be aware of this uncertainty, perform numerical simulations of the test and verify it based on collected data; these uncertainties should be included in planning. There have been financial consequences as well: any delay increases the costs (staff must be paid without interruption), on the other hand, delays allow for re-launching of tenders if a contractor is too expensive. The preparation phase consisted of the mobilisation of data management tools, numerical analysing of the system evolution, and establishing procedures for managing the test and follow-up actions.

2.6 Highlights

In situ large scale tests in URLs are expensive but needed to confirm THM-model-predictions and to identify weaknesses of the disposal system.

The results obtained during the preparation and initiation of full scale tests indicate that the selected approaches provide feasible solutions and sufficient answers for determined tasks; identified challenges provide a shopping list for future activities. A question arose to what extent experiments should and could represent real repository conditions.

The gained experience provides bases for optimisation of technologies and equipment.

Thorough planning is a key to the successful implementation of experiments (it shall include responsibility, allocation, procedure definition, control mechanisms and risk assessment)

There is a clear need for keeping know-how and continuity of the staff involved: the experiments may last up to 2 decades from the first idea to the final evaluation of the measured data.

One important issue seems to be keeping track of all documents and information (knowledge management) – appropriate measures shall be installed from the very beginning of the project to ensure its successful implementation and evaluation.

All large scale experiments have faced some delays – the thorough analysis of reasons and responses would help in planning future experiments and DGR construction.

Future activities will focus on optimising excavation and emplacement methodologies and relevant equipment, engineered barrier material performance, and increasing the monitoring capabilities in disposal systems.

3 Session 3: Excavation of Tunnels and Drifts

Session 3 consisted of 4 presentations on experiences gained during excavation work and on wire sawing in the URLs Mt Terri (Switzerland), Bure (France) and Äspö (Sweden).

The FE experiment tunnel excavation at the URL Mont Terri was successfully performed with standard mining equipment (e.g. pneumatic hammer and road headers). Daily geological mapping was a part of this activity as well as the installation of an adequate monitoring system. The real challenge in the process of preparing the FE experiment tunnel for utilization over a couple of years was the installation of the liner in particular the shotcrete liner. Several attempts were necessary to be successful.

The host rock at the URL Bure (as well as that of the expected site for the French repository Cigéo) is COX-clay. In total 5 shafts, 2 ramps several kilometres of connecting tunnels and approx. 1400 HLW emplacement cells (horizontal boreholes with 100cm diameter and 100m length) have to be excavated. Excavation exercises at dedicated test areas in the URL Bure were performed to learn and to investigate to what extend the selected technology can be transferred to the real repository. State of the art technology was applied like drill and blast technique, TBM, road headers and micro-TBM to excavate the openings and to construct liners (bolts, shotcrete and steel liners). Main challenges were the proper functioning of the TBM in COX clay (no experience available) and the speed to insert steel liners into the horizontal boreholes because of the fast creep behaviour of the COX clay.

As an alternative to the reference disposal concept KBS-3V SKB and Posiva do analyse the possibility of disposing Supercontainers into long horizontal boreholes, KBS-3H. For this purpose drilling of horizontal 300m boreholes with large diameters (1,85m) is necessary. The first experiments in this regard were performed in 2005 at the Äspö HRL. This drilling technique is not standardised and requires a step wise approach (test drillings/core drillings followed by extension drillings) and a series of deviation measurement and steering equipment to keep the drilling on track without deviations in vertical and lateral directions. This drilling technique cannot be applied in clay or salt formations.

In the context of optimizing the excavation technique in crystalline rock in particular in the vicinity of positions for plugs and seals SKB did investigate the wire sawing technology at the Äspö URL. Advantages were expected regarding more precise drift and tunnel surfaces, less impact on the EDZ of the tunnel contour, and saving money. At the end of test campaigns it was concluded that further development and testing is necessary to optimise the wire sawing technology.

3.1 Important messages:

- It was emphasised that a careful analysis of the geological environment at the URL test site is needed to be able to transfer the achieved results to other potential sites of a repository. By this procedure surprises can be avoided (e.g. excavation in faulted areas, anisotropic behaviour, etc.).

- The excavation of different types of openings in hard rock by appropriate technical means is state of the art: e.g. tunnel boring machine (TBM) or road headers for large drifts/tunnels; micro-TBM for emplacement cells. However, there are only few experiences in excavating tunnels and drifts in clay formations (e.g.: COX clay). Known and unsolved challenges still are the opening/excavation of tunnel-liners after long periods of time because of the time dependent increase of rock-pressure behind the liners and the concurrent activities of drilling horizontal emplacement cells and insertion of steel liners into the cells.

- Horizontal drilling of 300m boreholes in crystalline rock requires detailed preparation and a stepwise approach. Lessons learnt from test drillings at Äspö showed that pilot drilling with a small diameter (76 mm)can fulfil the requirements with regard to minimum longitudinal deviation (over a 100 m length scale so far). The (76 mm) pilot boreholes are planned to be stepwise reamed up to full drift diameter (1,85m). Further tests are necessary to demonstrate the accuracy for 300m long boreholes as well.

- For excavating tunnels in crystalline rock wire sawing appeared as a possible alternative. In contrast to the standard technology of drill and blast; this technique enables creation of tunnels with even and smooth rock surfaces (e.g. floor to drive on) and tunnels without lock-outs in roof and walls (facilitates more efficient backfilling). However, further development work and testing is necessary to optimise this technology.

4 Session 4: Production of Bentonite Blocks/ Granulates

Session 4 consisted of 6 presentations describing the production of bentonite blocks and granulates as backfill and sealing material for HLW-repositories in crystalline rock and clay formations.

4.1 Manufacturing issues

The water content in the bentonite is the main factor influencing the quality of blocks and pellets. Achieving the required dry density of bentonite requires optimisation of water content in compacted mixture respecting also requirements for storage conditions because of the hydroscopic material behaviour. A concept based on equilibrium of water content in blocks to the air humidity has brought positive and promising results.

Water content of the bentonite mixture was selected different for different purposes: this requires optimising manufacturing conditions for each particular purpose and bentonite block type. Also, equipment for bentonite transport needs to be selected with respect to its water content (e.g. clogging up screw conveyor while higher humidity material is transported).

All experiments used bentonite prepared in pilot plant or improvised industrial (= non-standard) conditions: the quality of products might differ according to the quality of input material (water content, homogeneity, or recycling of used bentonite) and reproducibility of the manufacturing process. It is anticipated that bentonite produced in an industrial scale will have more standard quality.

4.2 Lessons learnt

Due to the high sensitivity of bentonite to conditions under which blocks or pellets are produced and stored effective QA/QC measures have to be established and maintained. These measures are vital for the product quality and they must be set as a part of the manufacturing and handling technology development.

The technology (process and equipment) of block production still needs further development to keep the standard quality of the product.

Production of pellets/granulate is less challenging, however, the quality of raw bentonite is critical for the material production: e.g. bulk storage of raw bentonite results in more homogeneous product comparing to bags storage (different humidity of each batch).

Decision on whether to use isostatic or uniaxial compaction does not have clear bases: in both cases the required quality of blocks can be achieved. Each method has its pros and cons regarding the production rate, the need to further process produced blocks, and the control of optimal water content for reaching the required density.

Each size/shape of bentonite product requires its own manufacturing technology (process & equipment). The main challenge is to ensure keeping prescribed quality of the product and minimise any deviations.

Determination of design criteria for the input material and the final product is the basis for the establishment of an effective QA/QC system. As bentonite materials are vital for repository backfill and sealing concepts the production process has to be developed to an industrial standard reproducing the required bentonite quality in appropriate quantities.

5 Poster Session

About 30 posters were shown in a dedicated poster session. They provided complementary information and technical details extending information presented by conference speakers, as well as overview summaries of some national programmes/concepts, and projects LUCOEX, DOPAS. They contributed to delivering the conference key messages indicating that full scale experiments are needed:

- to fully understand principles of material behaviour (in particular bentonite) in repository conditions,
- to identify and fully understand responses of the host rock to construction and operation of a DGR,
- to verify management of repository construction processes (construction and QA measures) under repository like conditions,
- to test the reliable and safe operation of transport and emplacement technique, and
- to develop and validate monitoring approaches for the assessment of the disposal system performance.

6 Panel Discussion

As an introduction a presentation of a master thesis was given by Ann Caroline Wiberg on the Utilization of LUCOEX-results for others. The message she gave was that all LUCOEX results are valuable back-bones for the evolution of country specific waste management programmes.

Prior to the panel discussion four presentations from WMOs representing programmes in less advanced programs (SURAO: Vitezslav Duda; PURAM: Kalman Benedek; INR: Marius Iordache; RWM: Robert MacLaverty) were given on their national programme status and plans related to large scale /full scale experiments. They all stressed that international cooperation is a key facet in research strategy and that URL Research can help to achieve progress in national WM programme. To a certain extent they do operate national URLs like SURAO does in the Joseph-Gallery. All of them expressed the strong wish to benefit from achievements in particular from EU funded RD&D projects. In addition it was mentioned that they are interested in information exchange / cooperation / participation in future RD&D-actions. In this context a few points of particular interest were mentioned e.g. waste package storage, waste treatment, repository concept development, plugging and sealing, and disposal programme planning.

The five panellists (Johanna Hansen, Jean-Michel Bosgiraud, Alan Hooper, Stig Pettersson and Tim Vietor) were discussing pros and cons of Full Scale Tests in URLs. All the panellists are experienced scientists and engineers and familiar with the complex and time consuming work of developing and testing of new materials, processes, techniques and equipment. They commonly listed the convincing arguments/reasons (**pros)** for performing/ participating in large/full scale tests:

- cost saving: access to documented data (open platforms), participation in existing URLs instead of constructing own facilities (large or small size), conformation laboratories vs generic laboratories,
- confidence building: people can get in contact with repository components prior to repository construction and operation, proper scientific work,
- staff training (security issues, mastering of procedure, knowledge transfer),
- development of quality management systems for repository construction and operation/closure, and
- operational safety: full-scale tests provide realistic data on reliability and safety of repository components and techniques, avoiding surprises and malfunction in real repository construction /operation (early involvement of safety authorities).

However, a few arguments against (**cons**) performing/ participating in large/full scale tests were mentioned. All these are more or less commercial aspects; like the need of early investments, the share of financial burden, the approach that with time technologies might be state of the art an could be bought on market.